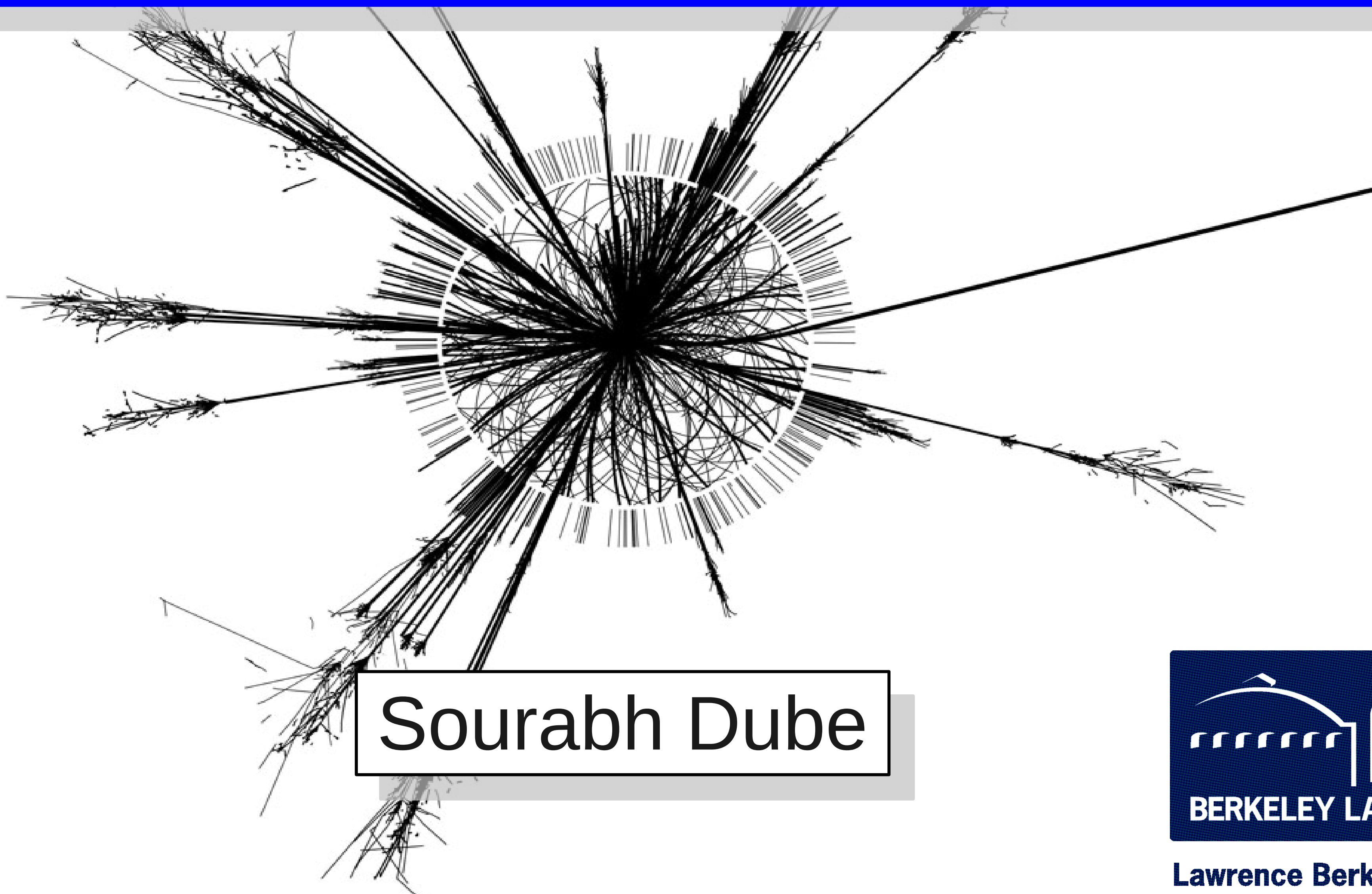
Searching for black holes at ATLAS



Sourabh Dube

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Physics 290e

9th November, 2011

Last week, we heard from Grant and Alex about Extra Dimensions.

Grant : overview of ED theory

Alex : searches involving gravitons

Today, another possible consequence of ADD ED – mini black holes!

In the transplanckian region, $\sqrt{s} >> M_D$, quantum gravity effects subleading to classical gravitational effects.

Recall, M_D is the Planck scale in D dimensions, (D = 4 + n)

If impact parameter of colliding partons $b < R_s$ (Schwarzschild radius in D-dim), gravitational collapse and black hole production.

Predicted cross sections are high.

Classical approx. for production and decay only valid if $M_{BH} >> M_D$

We introduce M_{TH}, threshold mass of produced black holes – black holes produced with mass from M_{TH} to $\sqrt{s}$.

Parameters:
M_D, M_{TH}, n

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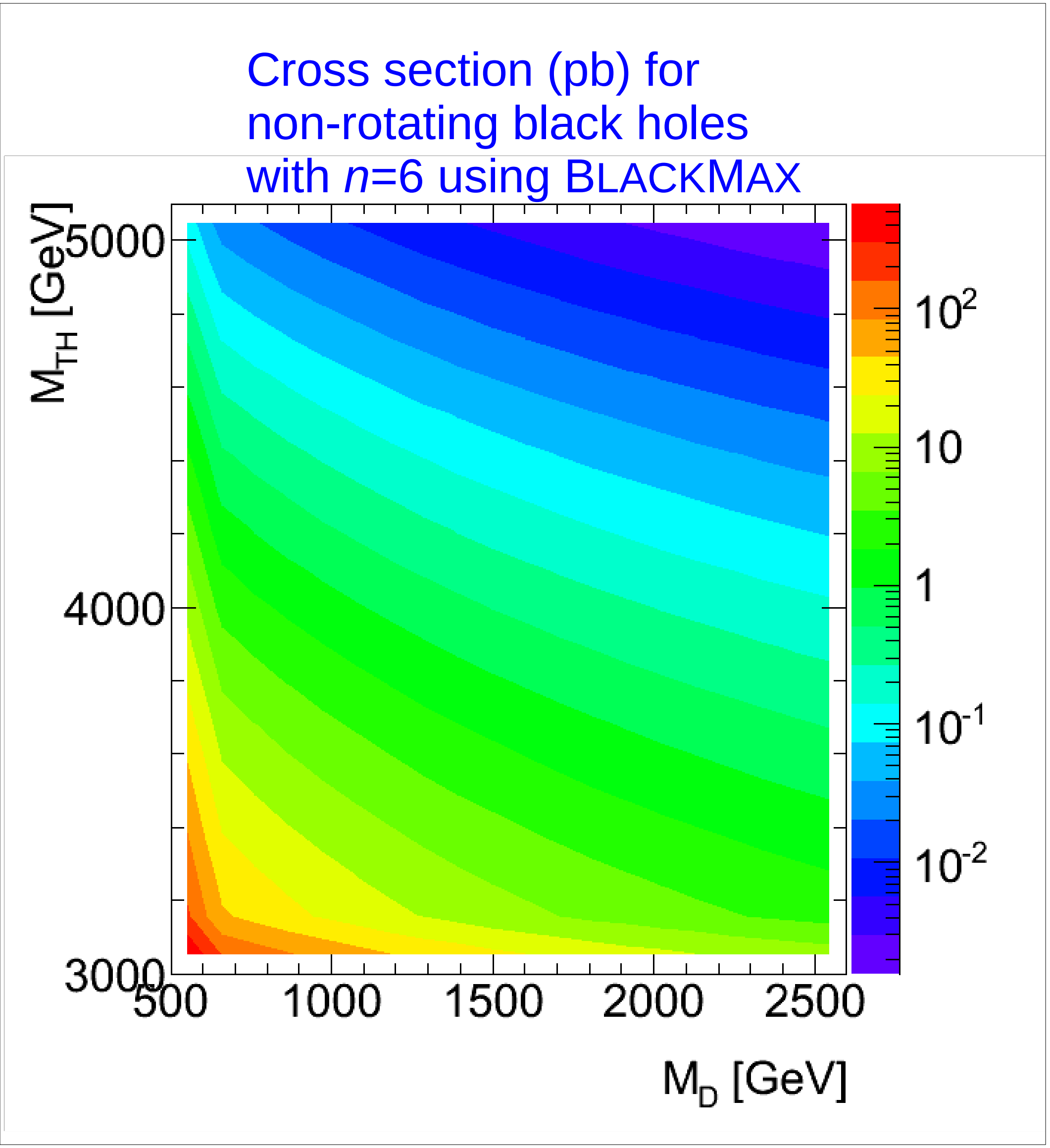

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Parameters:
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Black holes decay via Hawking radiation

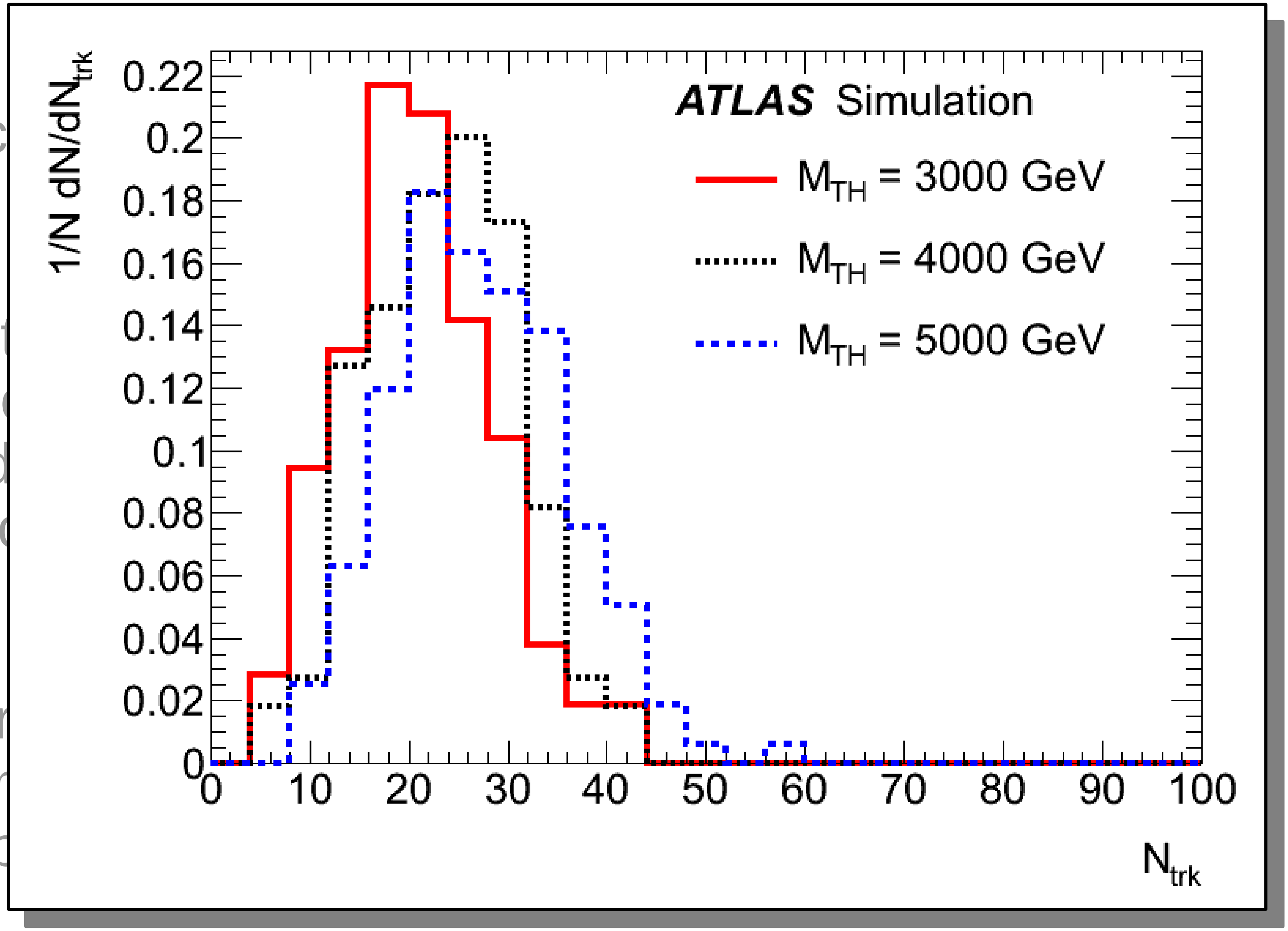
Decay to all particles in the SM,
multiplicities of emitted particles
depends on dof of particle types
and decay modes of unstable particles.

BH starts with mass M_{TH},
Loses mass till $M_{TH} = M_D$,
Then “bursts”

(Burst: lowest number of particles such that
this conserves energy, momentum, gauge
quantum numbers – as defined by Blackmax)

Black holes dec

Decay t
multiplic
depend
and dec



BH star
Loses r
Then “b

Number of tracks (pT > 10 GeV) for different rotating black hole models. M_D = 1.5 TeV, n = 6.

(Burst: low
this conse
quantum numbers – as defined by Blackmax)

Searches for black holes at ATLAS

Multijet : 35 pb^{-1}, $N_J(p_T>50)$ >4, $\sum p_T$ > 2 TeV Link

Lepton+jets: 1 fb^{-1}, N_{obj} (pT>100) >2, $\sum p_T$ > 1500 GeV Link

Dimuon+tracks: 1.3 fb^{-1}, $\mu(p_T)$ > 25, 15 GeV, $N_{trk}(p_T>10) \geq 10$
also with 35pb^{-1} (2010)

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Focus on the last one...

Out for publication, uses most data

& I worked on it!

Analysis Strategy

Parameters of model are M_D, M_{TH} and n

- Decay of blackholes has multiple high p_T objects.
- Like-sign dimuon search
- Use high p_T track multiplicity to define signal-rich region.
- Perform a counting experiment in the signal region.
- Either find black holes... or
- Obtain exclusion contours in plane of M_D and M_{TH} for different n (for rotating/non-rotating black holes).

Event selection

Muons:
(combined from ID and MS tracks)

At least two muons

Come from same vertex

Tracks :
p_T > 10 GeV

Same as ID tracks of muons

Come from same vertex as muons.

Muons $\subseteq$ Tracks

Event Selection:

μ_1 p_T > 25 GeV, μ_2 p_T > 15 GeV

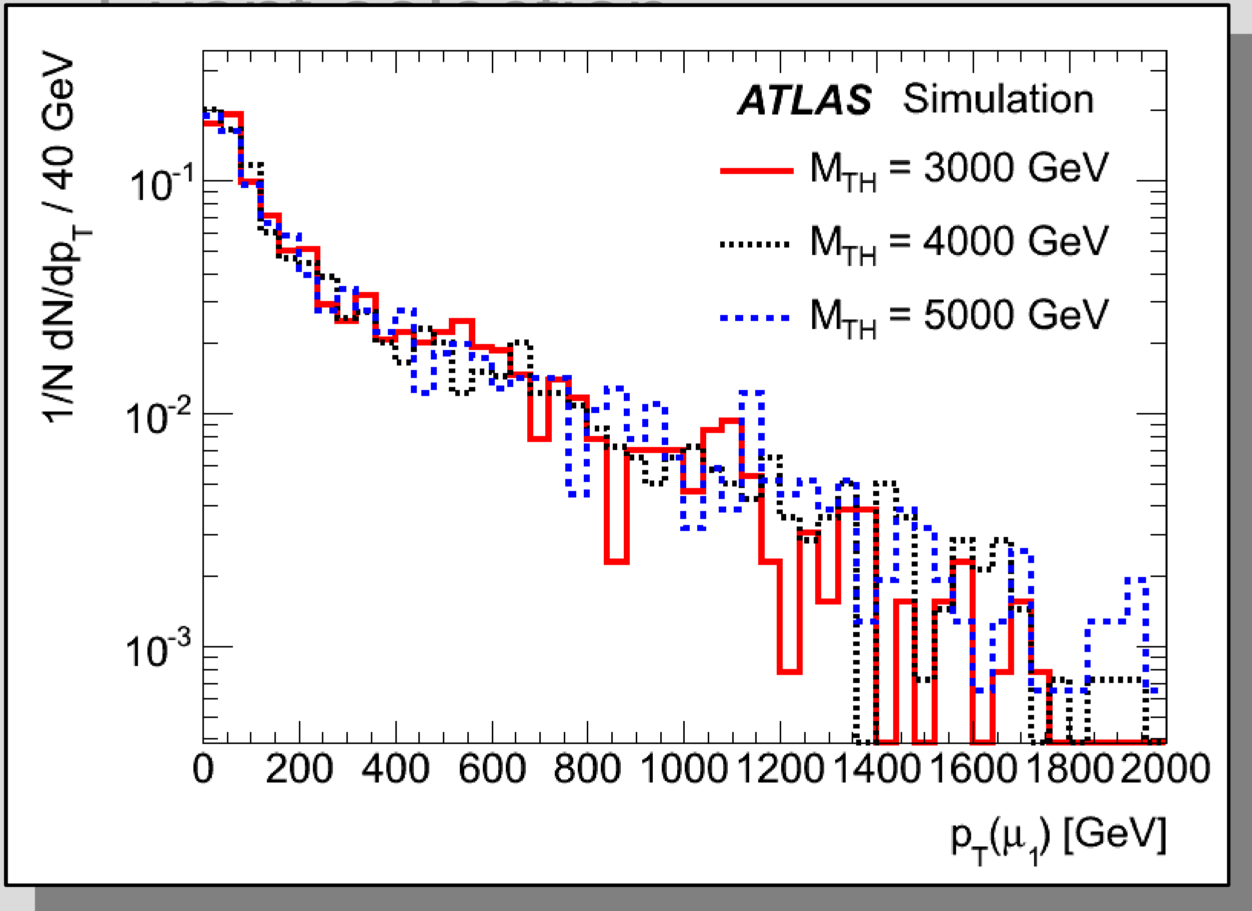
Leading muon:

Isolated, $p_T(\text{cone}=0.2)/p_T < 0.2$

Low d_0 significance, $|d_0/\sigma(d_0)| < 3$

Charge(μ_1) = Charge(μ_2)

NTracks ≥ 10 (Tracks as defined above)



:
0 GeV
as ID tracks of muons
from same vertex as muons.

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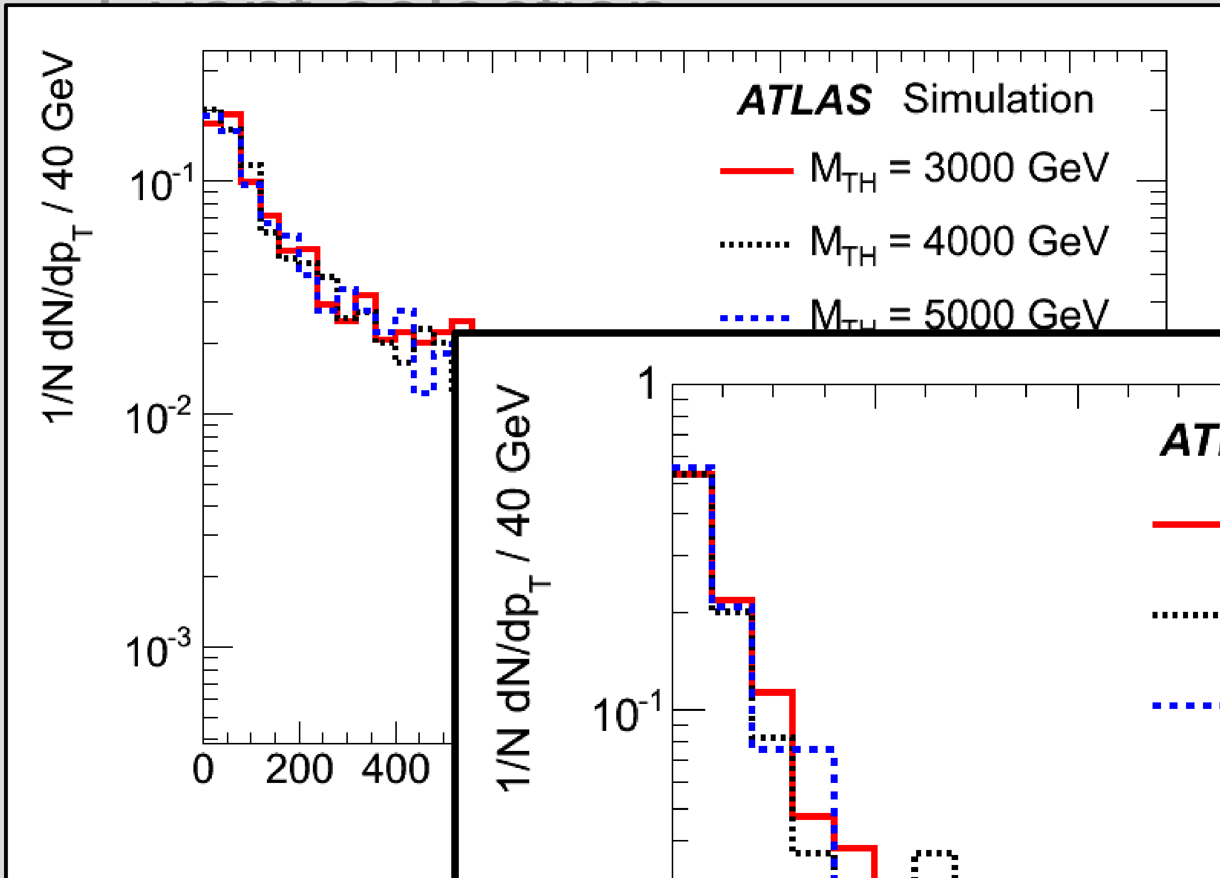

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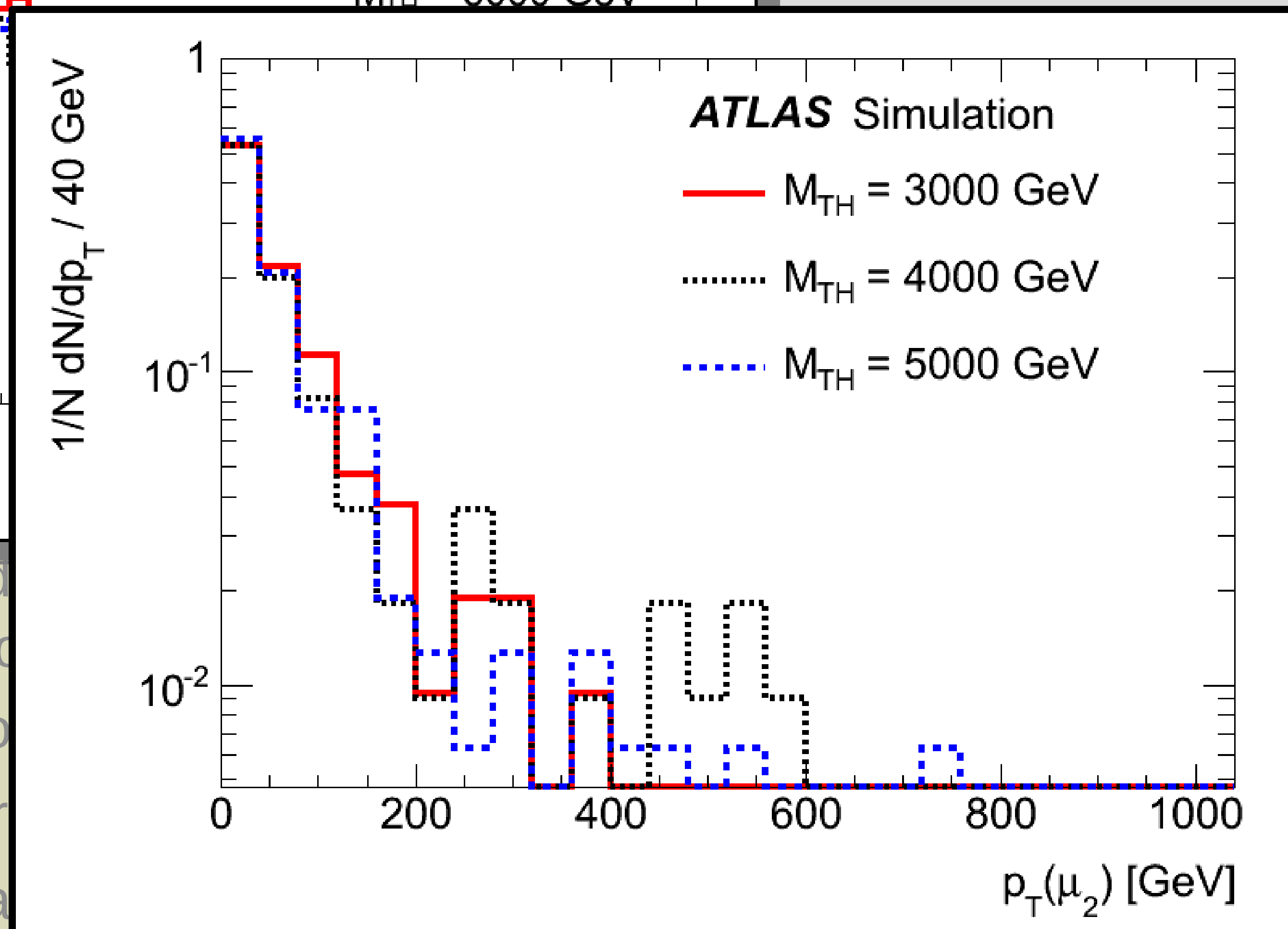

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Backgrounds

Split background estimate into two types

Like-sign dimuons from uncorrelated decay chain

- For example W+jets, Z+jets, low pT QCD.
- Fake muon can come from heavy-flavor decay or it can come from π/K decay, punch-throughs

Like-sign dimuons from correlated decay chain –

- For example $t\bar{t}$, $b\bar{b}$
- Either muon can be prompt
- Non-isolated muon likely comes from *b*-decay
- Also WZ, where both muons are prompt.

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From data

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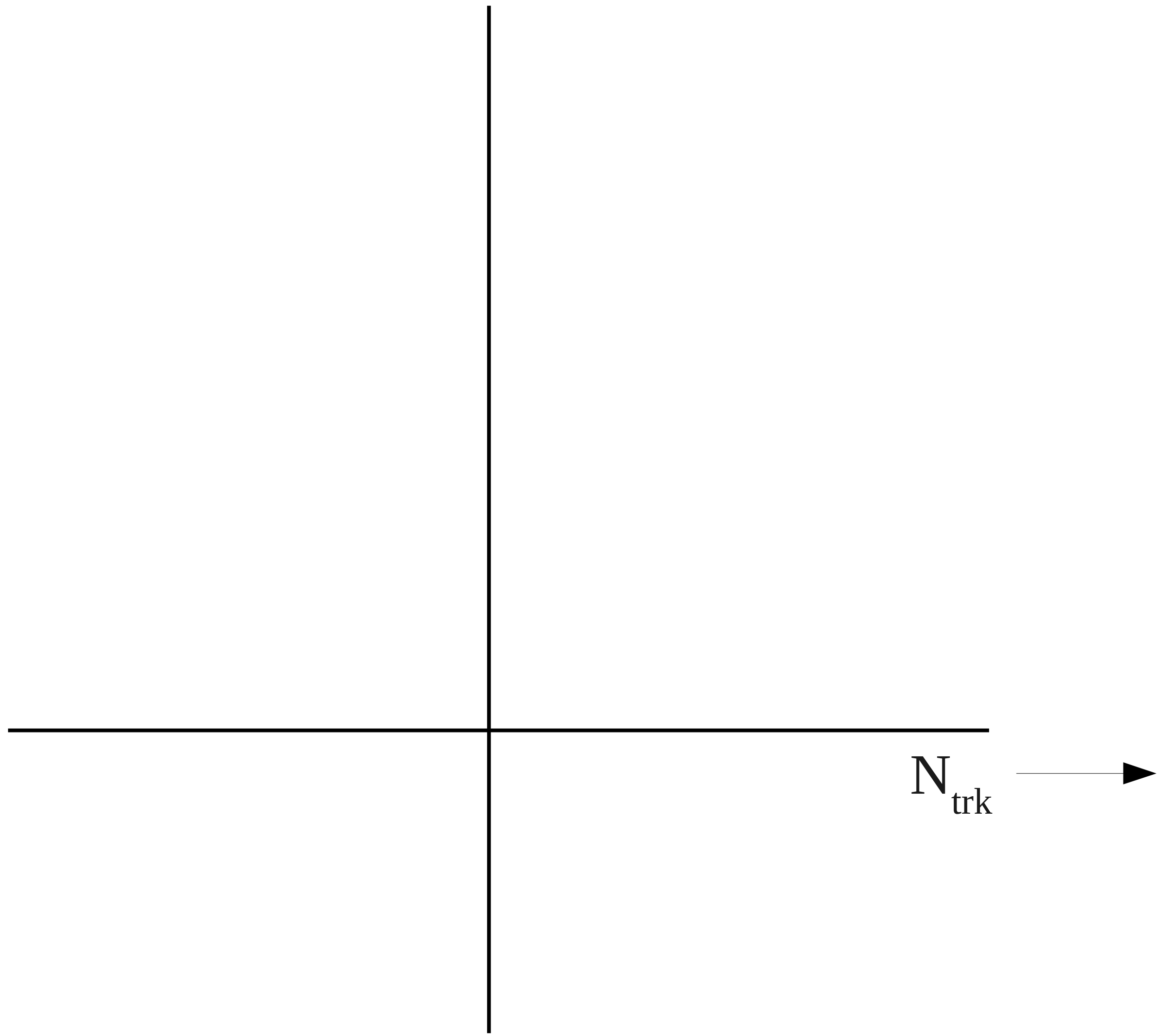
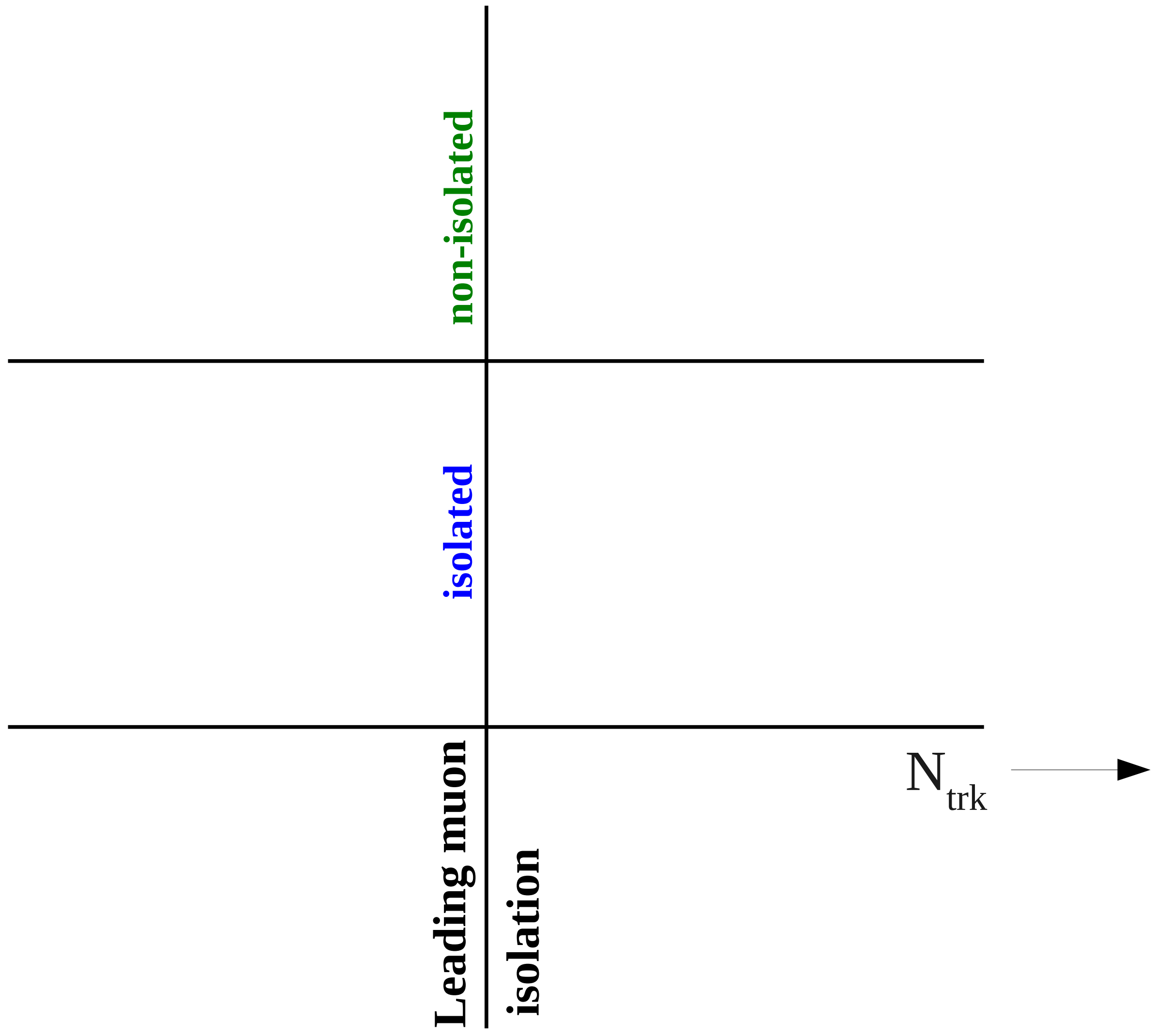
From MC

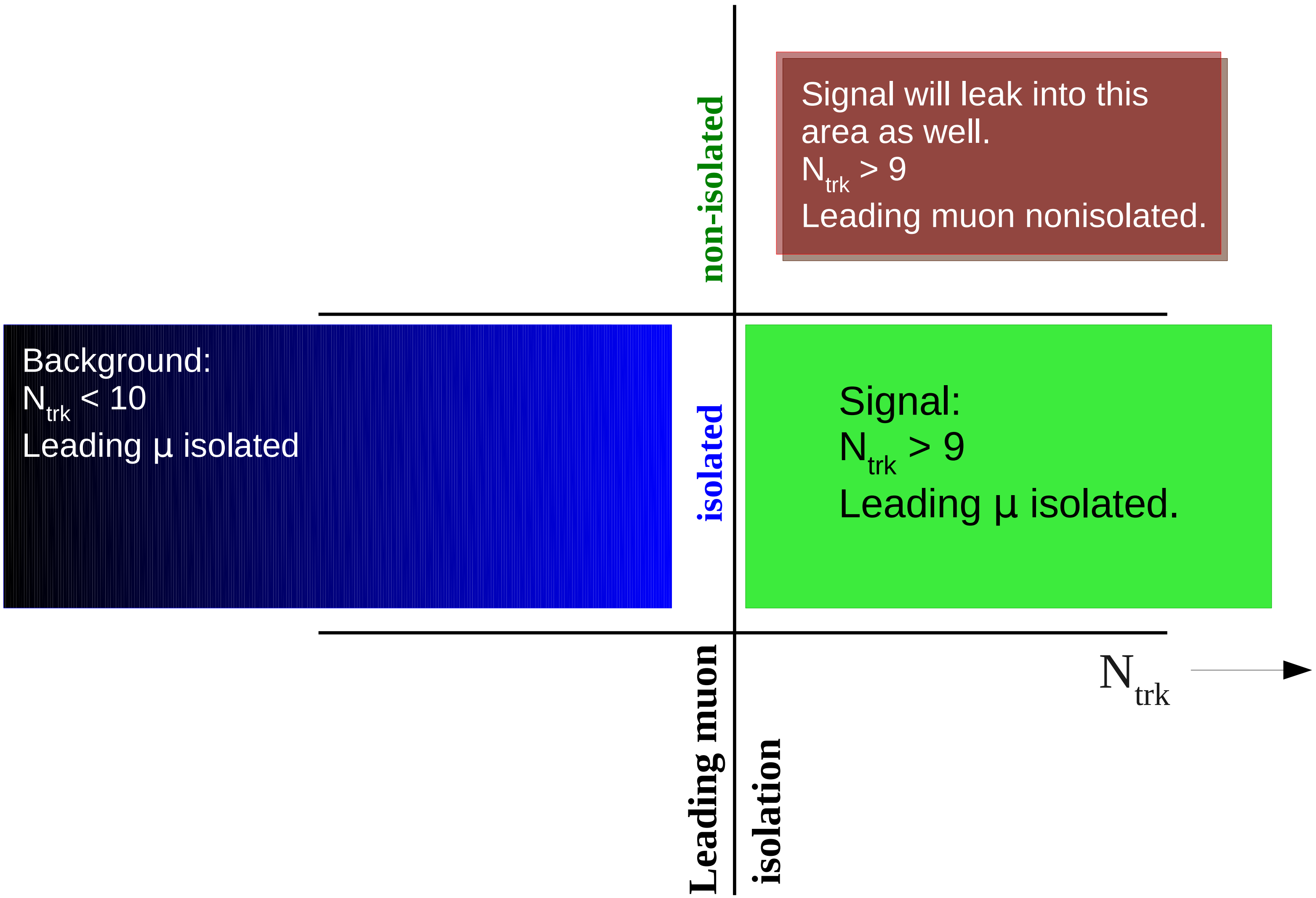
Background regions



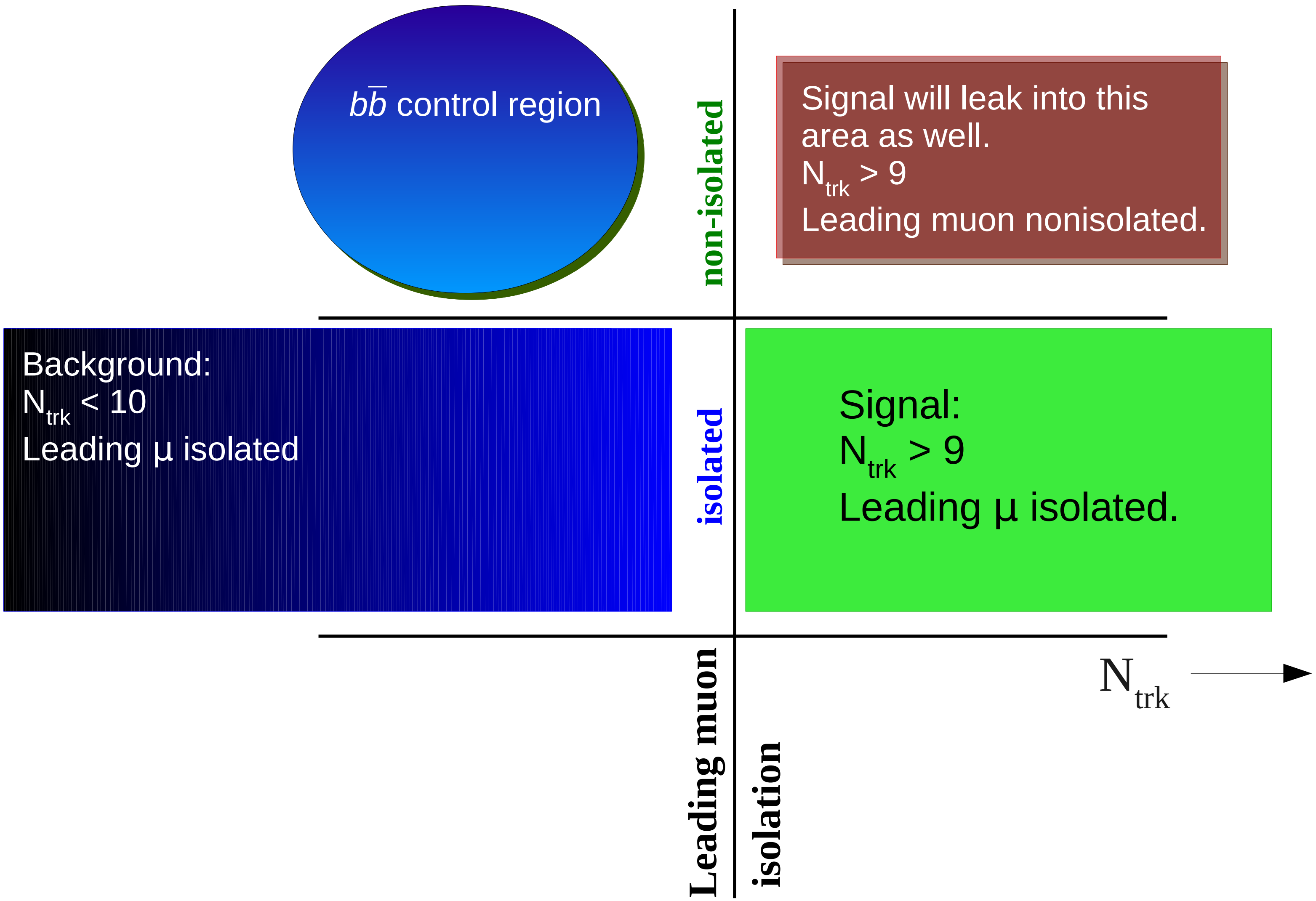
Background regions



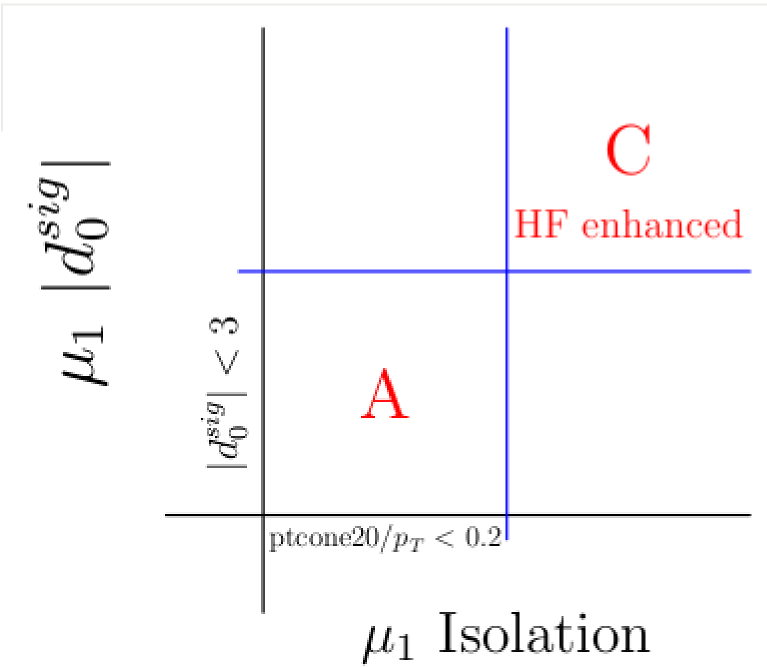
Background regions



Background regions
$b\bar{b}$



Step 1: Estimate $b\bar{b}$ in background region ($N_{trk} < 10$) by using heavy flavor control region and the $b\bar{b}$ MC.



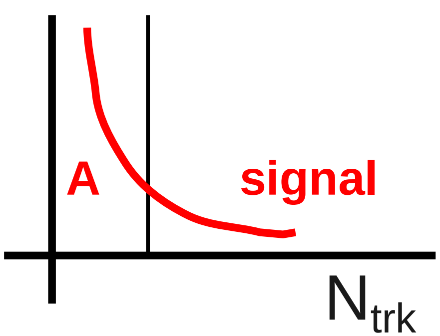
Use $R_{MC} = A_{MC}/C_{MC}$

$$A_{data} = R_{MC} \bullet C_{data}$$

In other words,

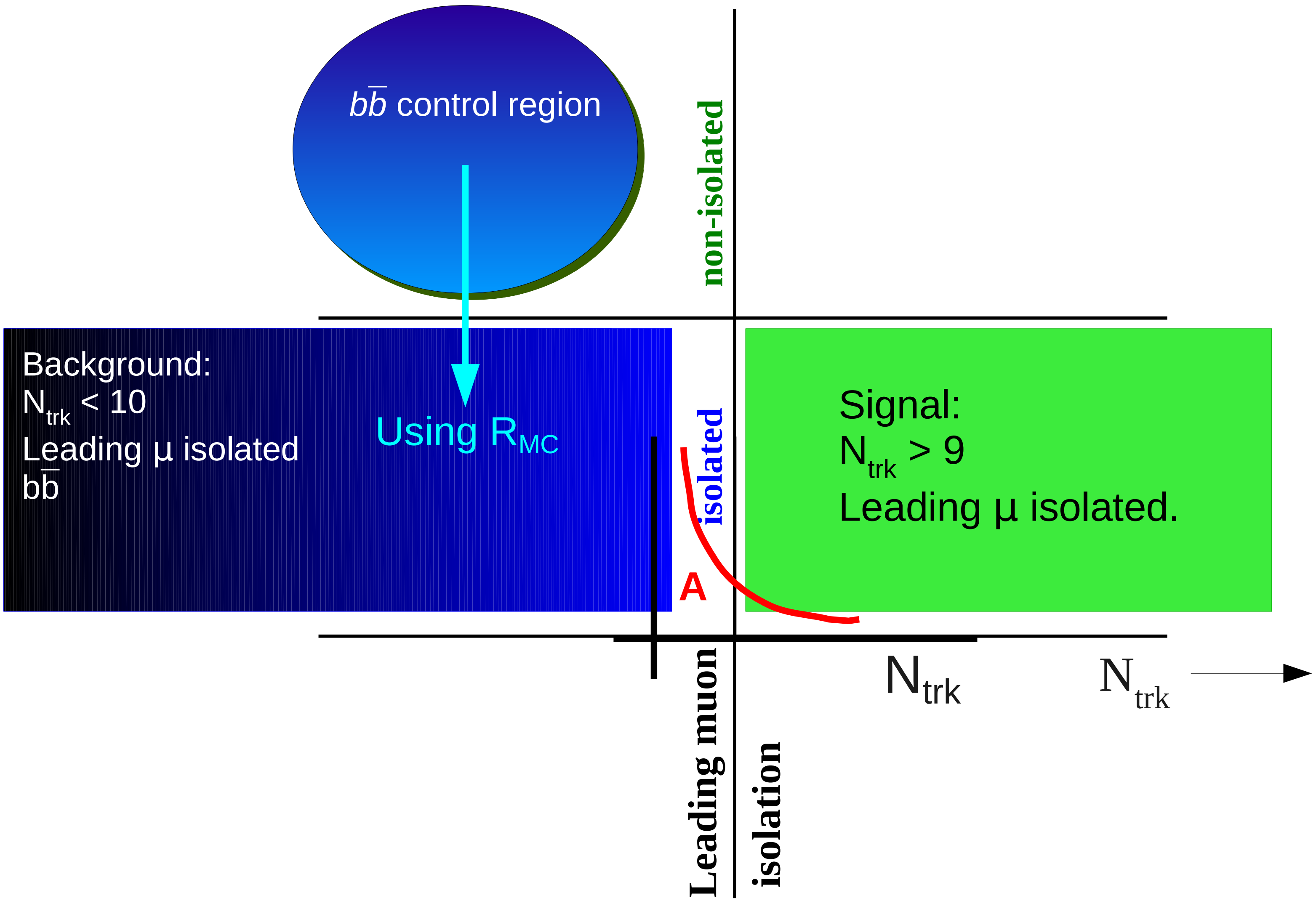
- MC gives ratio of events in A vs C,
- Then normalize MC using region C.

Use shapes of kinematic distributions from C_{data}.



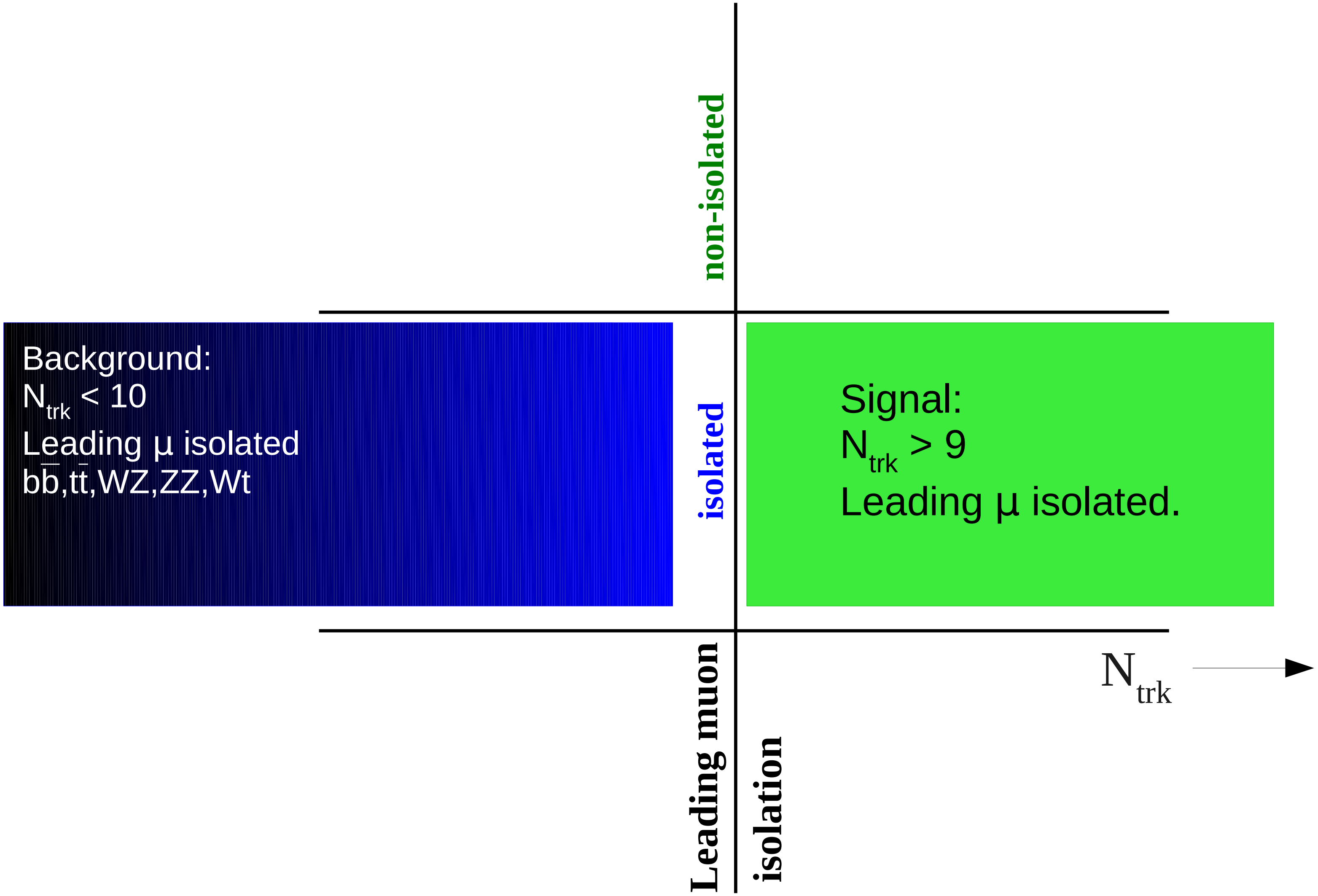
Step 2 : Fit N_{trk} variable and extrapolate to signal region.

Background regions
$b\bar{b}$ done

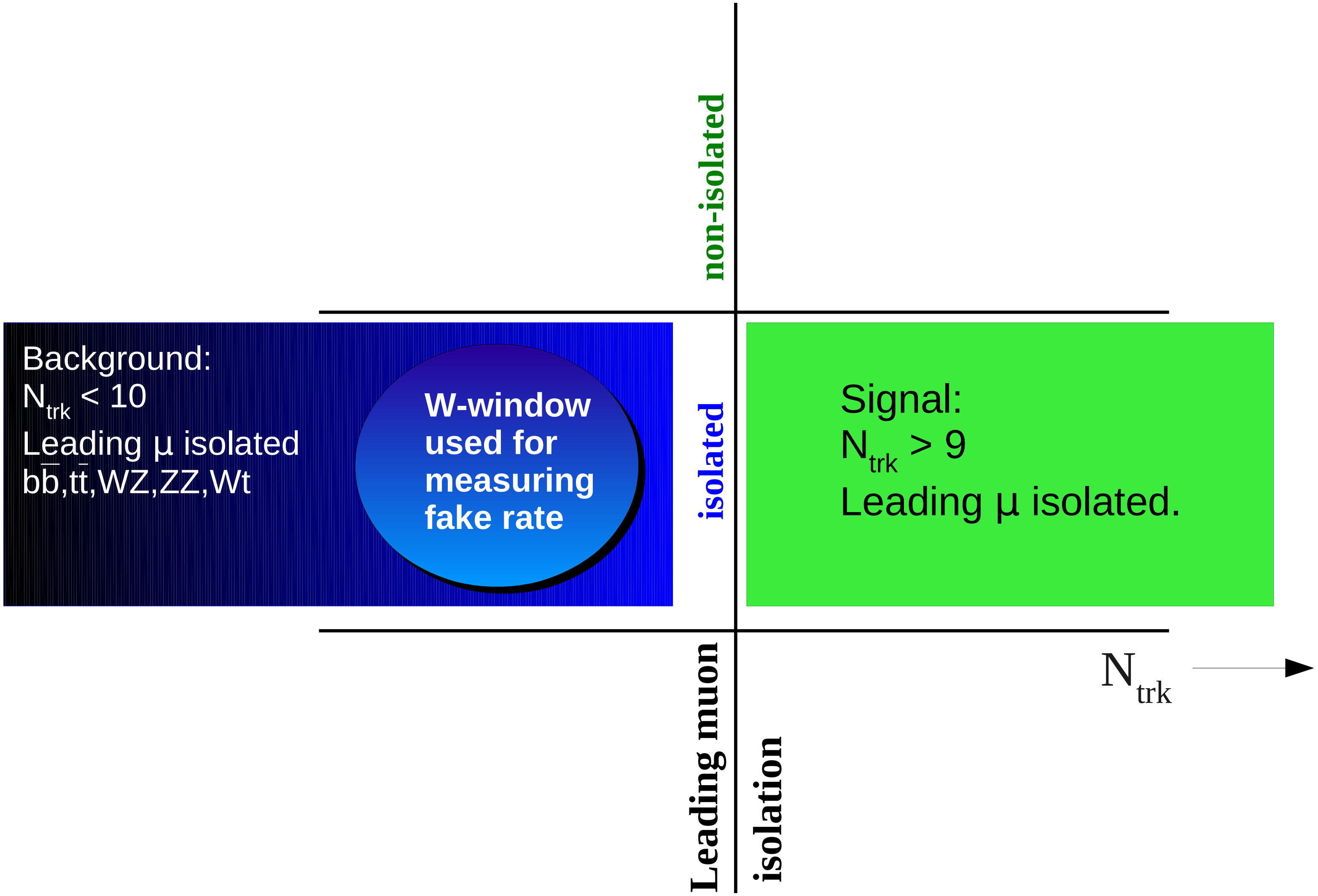


Background regions
$t\bar{t}$,WZ,ZZ,Wt done

$t\bar{t}$,WZ,ZZ,Wt estimated from MC samples.(WZ,ZZ,Wt negligible)



Background regions
Fake (uncorrelated) background



Background estimate: $\mu+\mu_{fake}$

Measure a **per-track** rate of track ⟶ muon

1. Select ***W*** events with one extra track
   Track has same charge as ***W***-muon.
   This is denominator.
2. Subset of events with 2nd muon with
   same charge as ***W***-muon and matched to track.
   This is numerator.

$$f = \frac{N(W \to \mu^{\pm}\nu + \mu^{\pm})}{N(W \to \mu^{\pm}\nu + \text{track}^{\pm})}$$

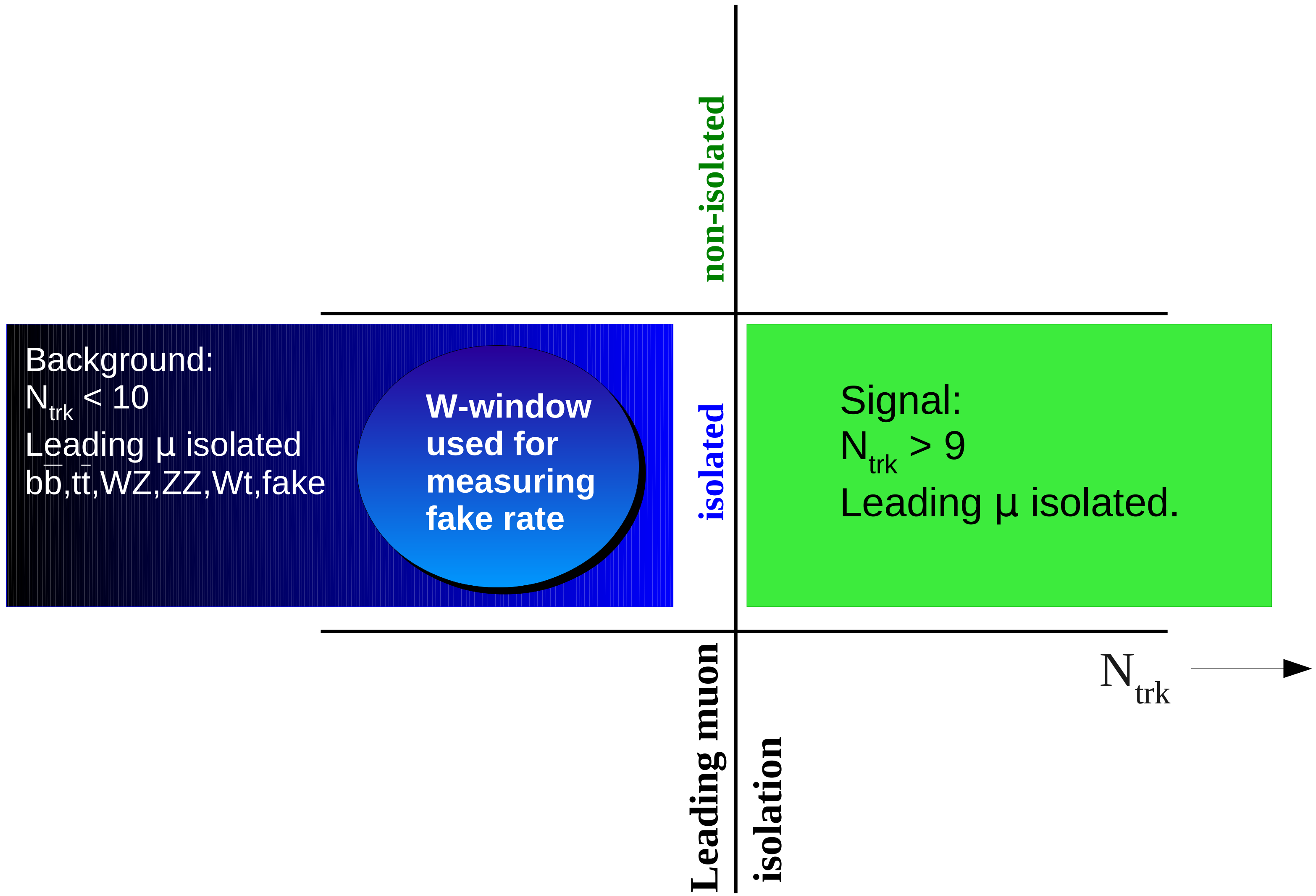
$$N(\mu^{\pm}\mu^{\pm}) = f \bullet N(\mu^{\pm}+\text{track}^{\pm})$$

3. Apply rate to all μ+track events in data
   To get estimate of $\mu+\mu_{\textbf{fake}}$ background.

Obviously, $t\bar{t}$ and $b\bar{b}$ events would be selected in the W-window.
These are removed by estimating from MC.

Fake rate measured as function of track p_T.

Background regions
All backgrounds estimated.



Systematic uncertainties (non-exhaustive list)

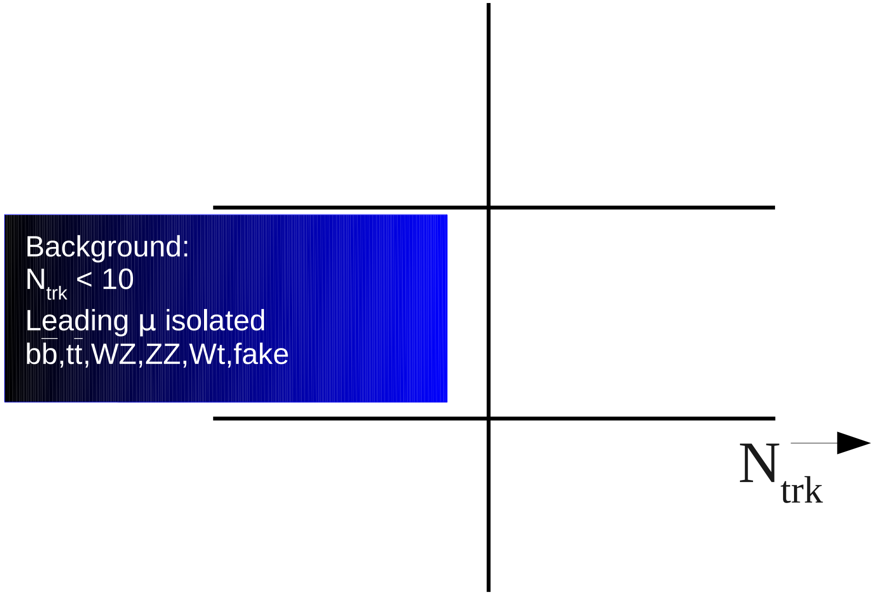
- $t\bar{t}$: cross section (9.6%), Generator (5.1%), ISR/FSR(7%)

  Total = 14%
- Fake: Subtraction of $t\bar{t}$,$b\bar{b}$; measurement of fake rate

  Total = 20%
- $b\bar{b}$: extrapolation to $N_{trk} \geq 10$,

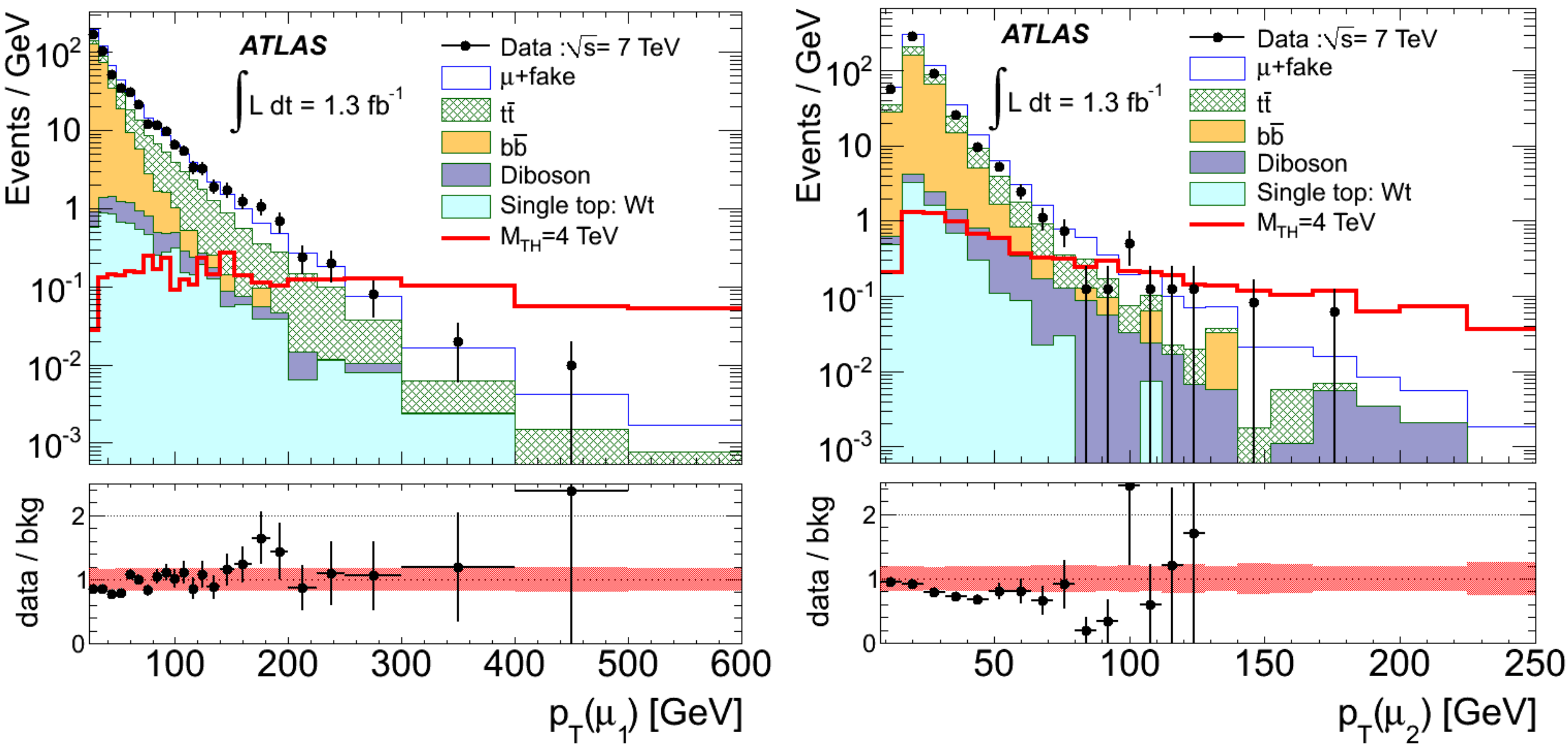
  Total = 100%

Background region
$N_{trk} < 10$



Process	Events
b/c	$2120 \pm 30(\text{stat}) \pm 200(\text{syst})$
$t\bar{t}$	$750 \pm 100(\text{syst}) \pm 30(\text{lumi})$
μ+fake	$1300 \pm 2(\text{stat}) \pm 260(\text{syst})$
Wt	$53 \pm 2(\text{syst})$
$WZ + ZZ$	$36 \pm 1(\text{syst})$
Predicted	$4270 \pm 30(\text{stat}) \pm 340(\text{syst})$
Observed	3775

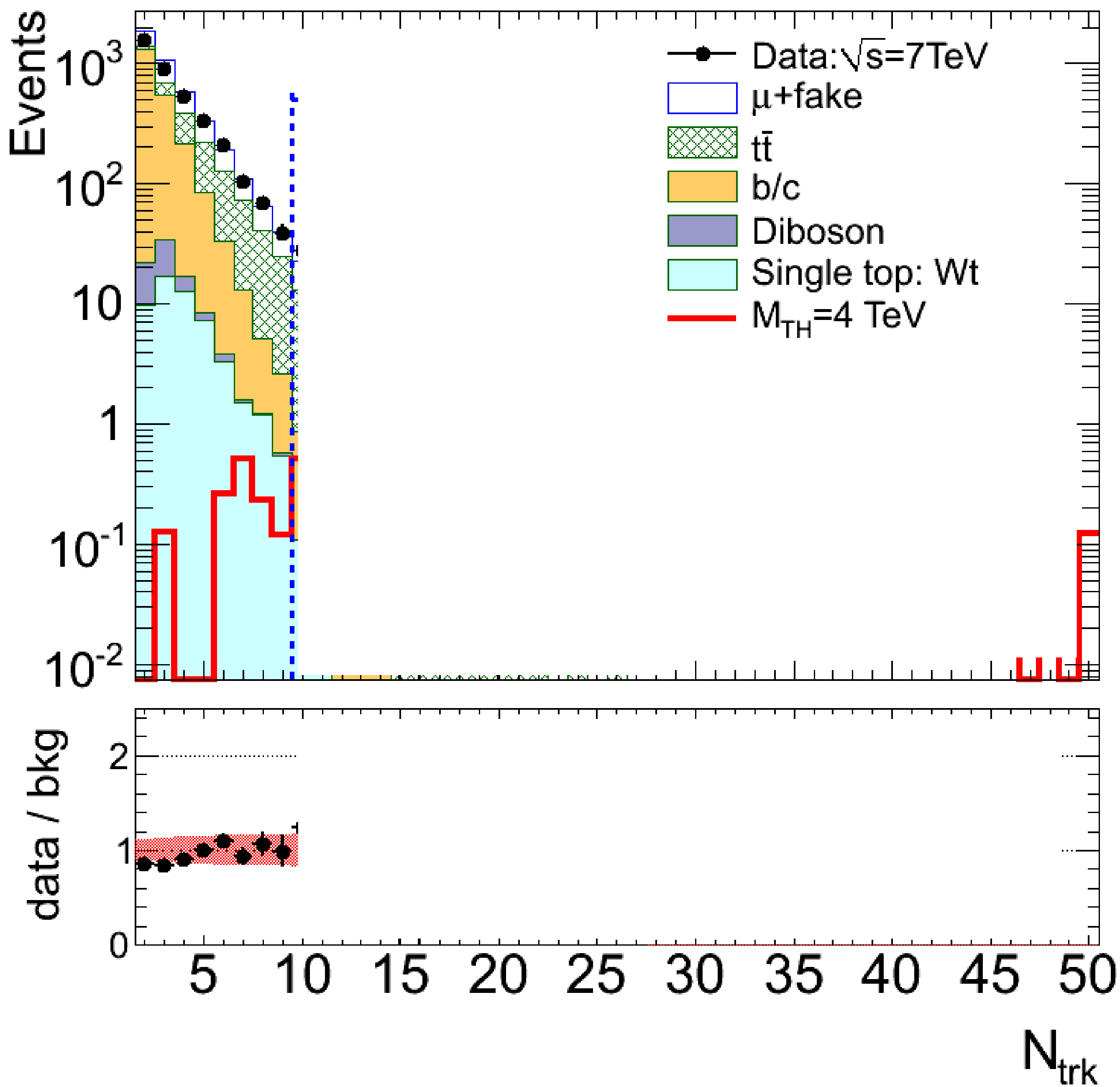
Like-sign dimuon events : p_T



Leading muon

Subleading muon

Like-sign dimuon events: Track multiplicity



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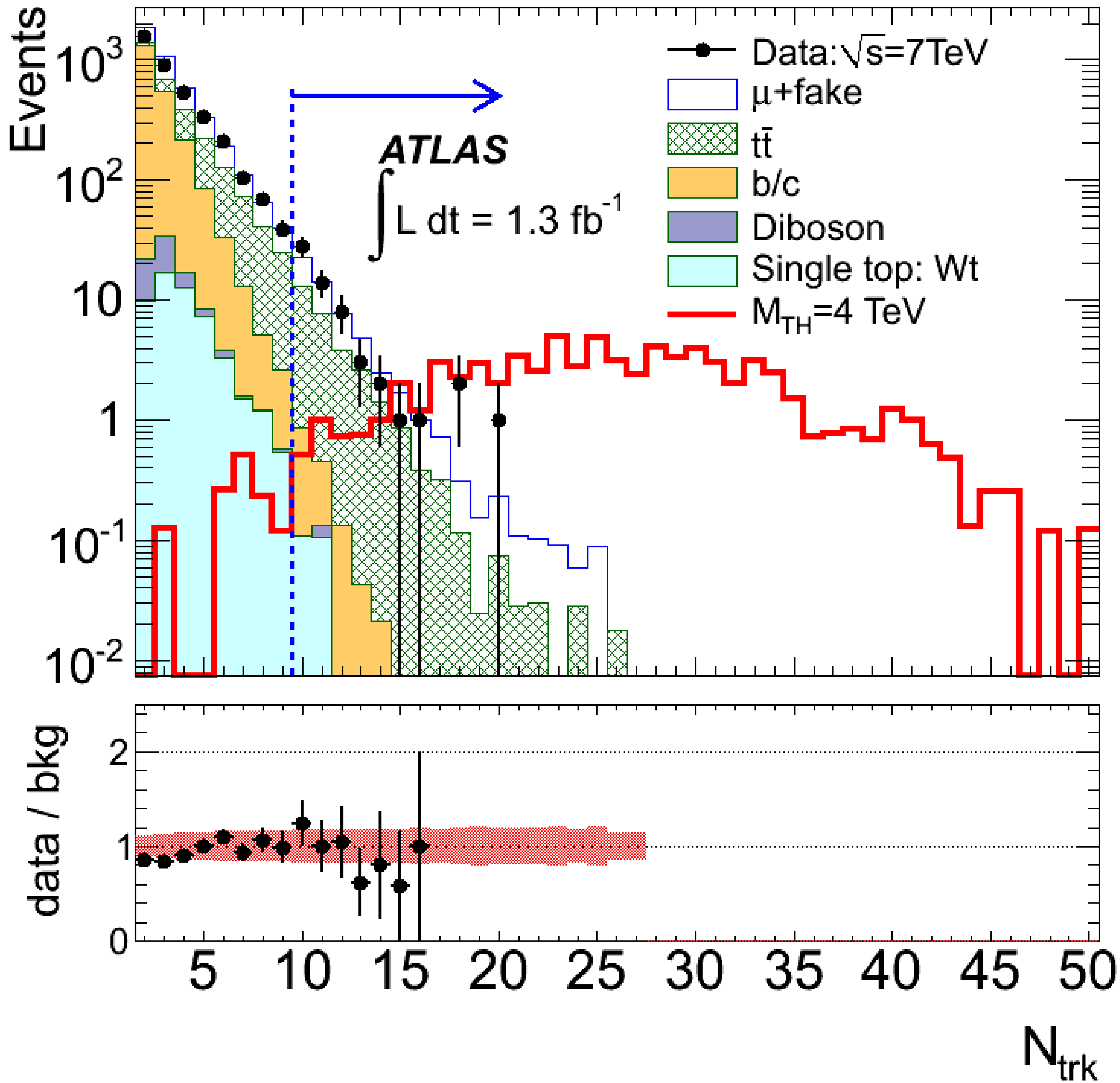
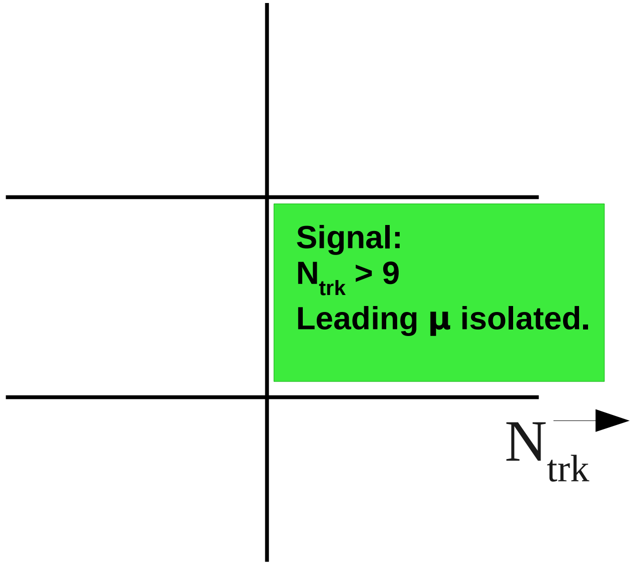
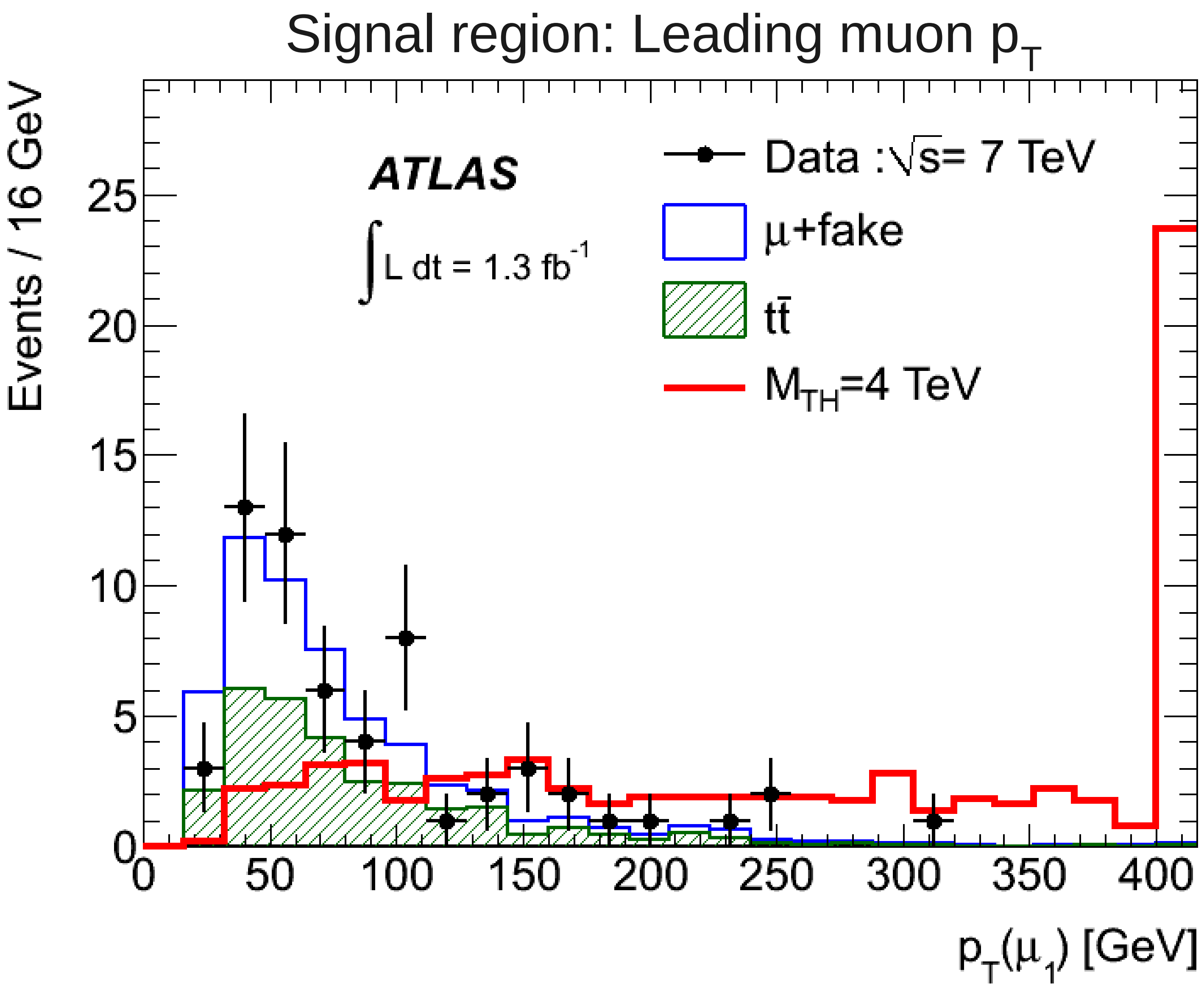
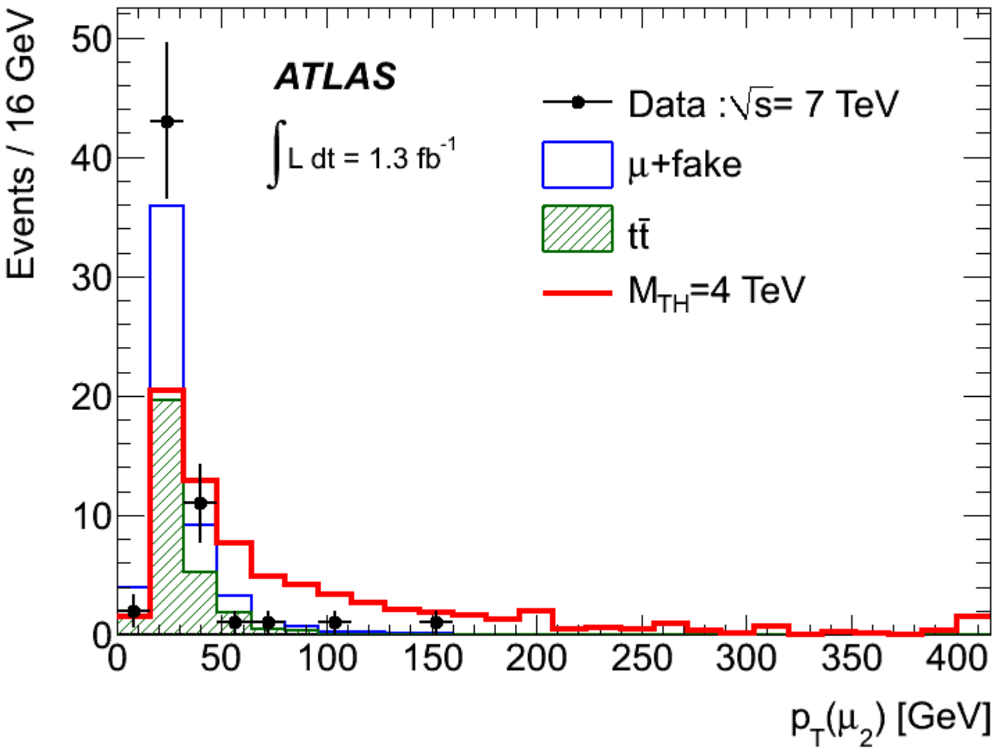


Signal region
$N_{trk} \geq 10$

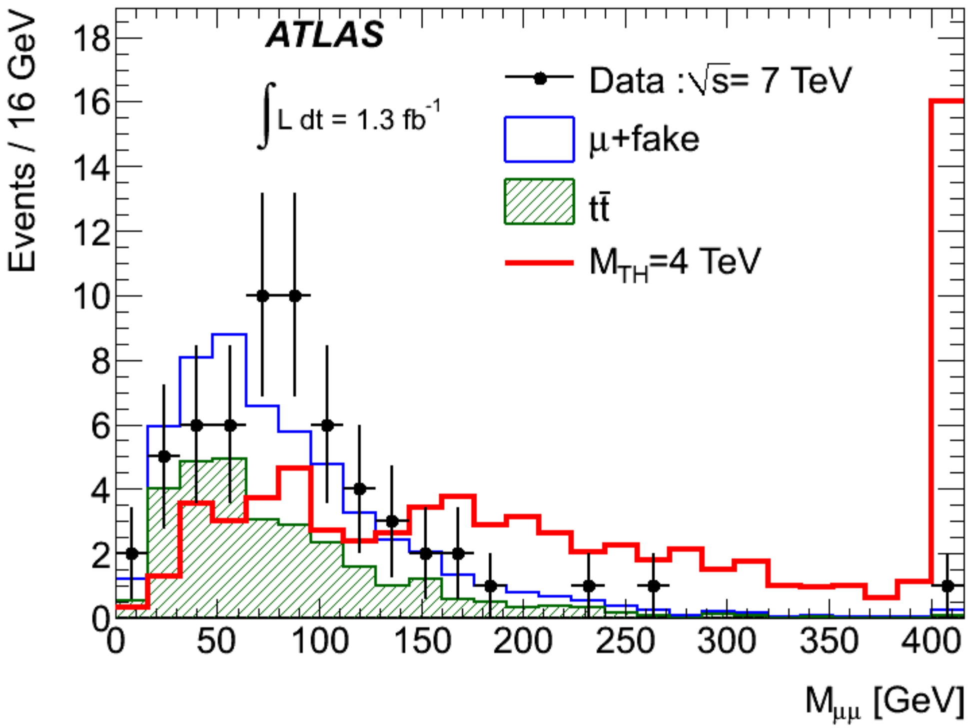


Process	Events
b/c	0.77 ± 0.77(syst)
$t\bar{t}$	29.2 ± 4.1(syst) $\pm$ 1.1(lumi)
μ+fake	25.6 ± 0.3(stat) $\pm$ 5.2(syst)
Other backgrounds	0.25 ± 0.11(syst)
Predicted	55.8 ± 0.3(stat) $\pm$ 6.7(syst) $\pm$ 1.1(lumi)
Observed	60
Signal $M_{TH} = 4$ TeV	72.1 ± 4.5(syst)


Signal region: Leading muon p_T
ATLAS
$\int L\,dt = 1.3\ fb^{-1}$
Data : $\sqrt{s}$ = 7 TeV
μ+fake
$t\bar{t}$
M_{TH}=4 TeV
Events / 16 GeV
$p_T(\mu_1)$ [GeV]
0
5
10
15
20
25
0
50
100
150
200
250
300
350
400



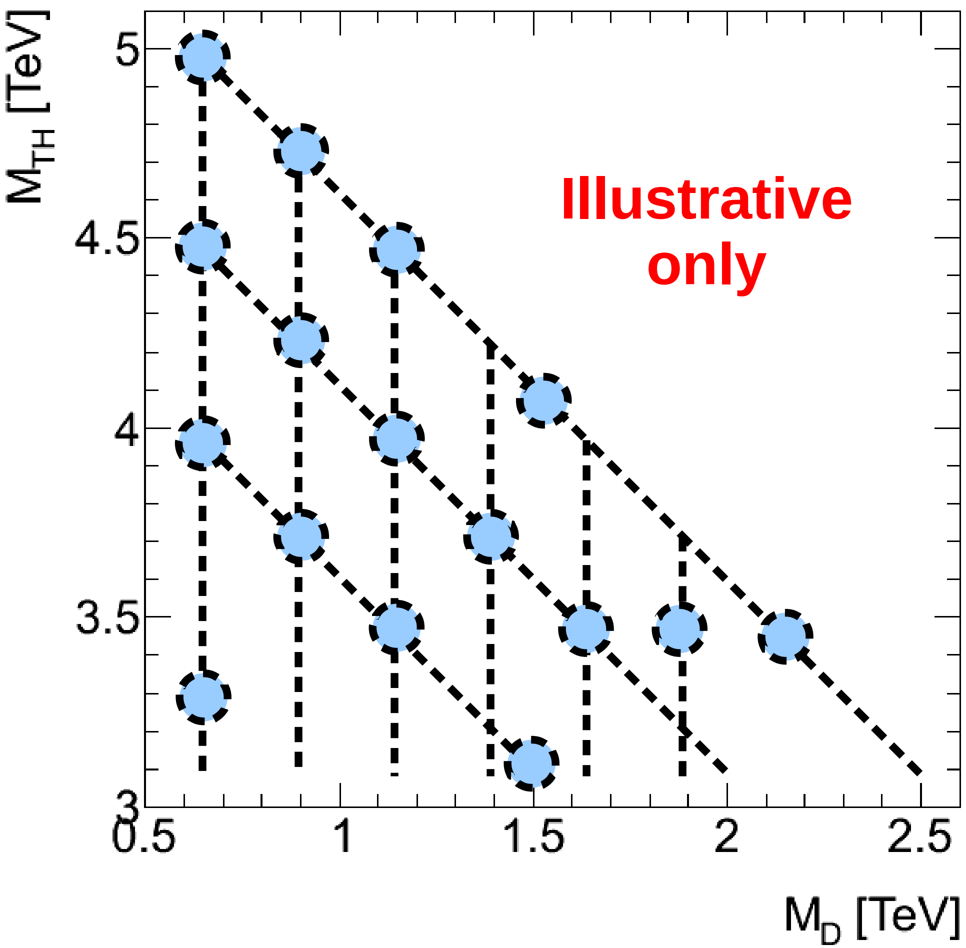
Signal region: subleading muon p_T



Signal region: $M_{\mu\mu}$

Interpreting results as exclusion contours

Using CLs method
Observed limit on σ x BR x Acceptance = 0.018 pb



Exclusion contours to be obtained in the plane of M_{TH} and M_D.

- About 1400 samples produced at generator level (truth) to obtain acceptance.

- Cross checked with a subset of fully simulated samples.

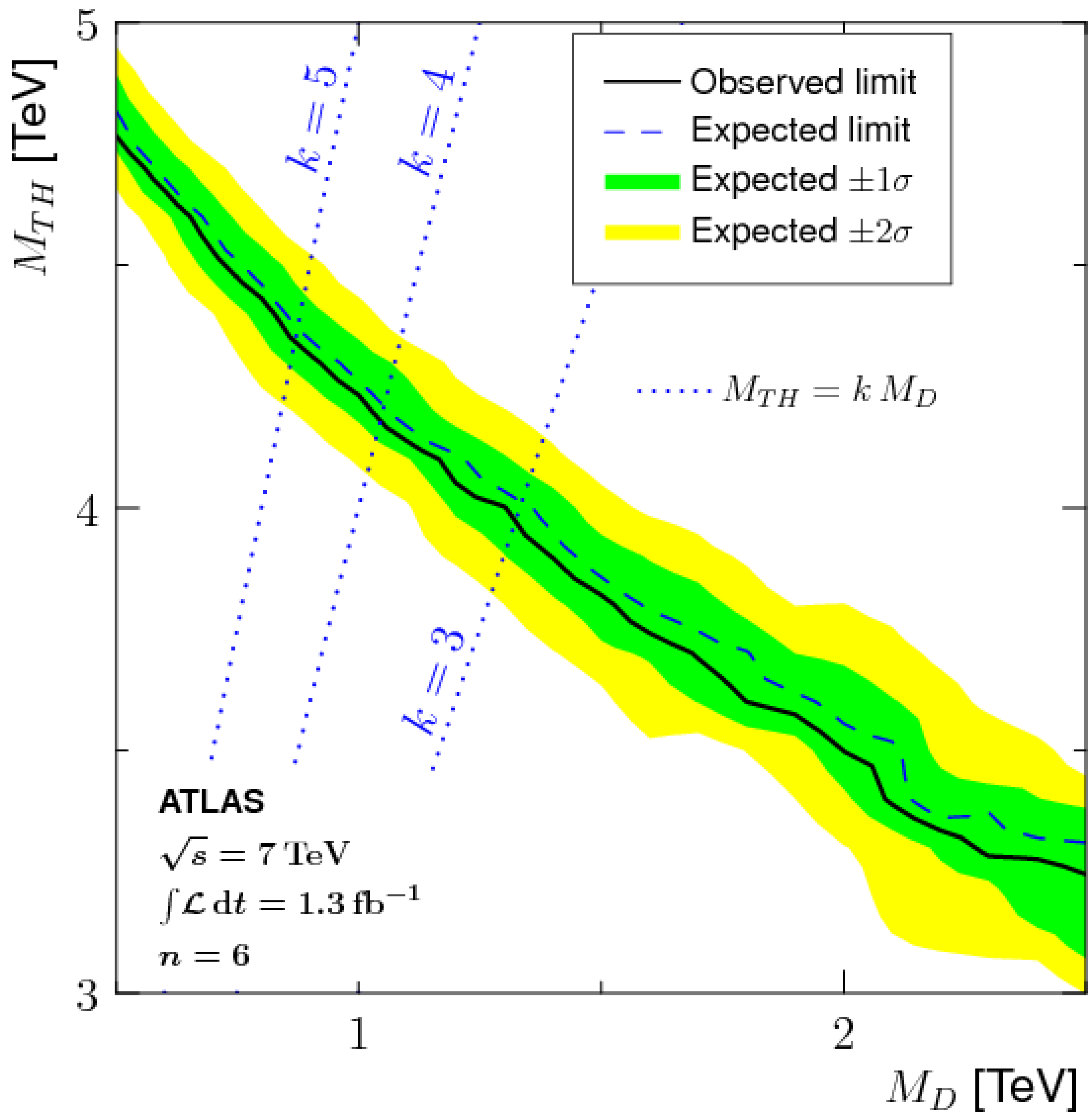
- Using this comparison, truth level acceptance scaled by 0.7 ± 0.1

Uncertainties on the signal (~15%)

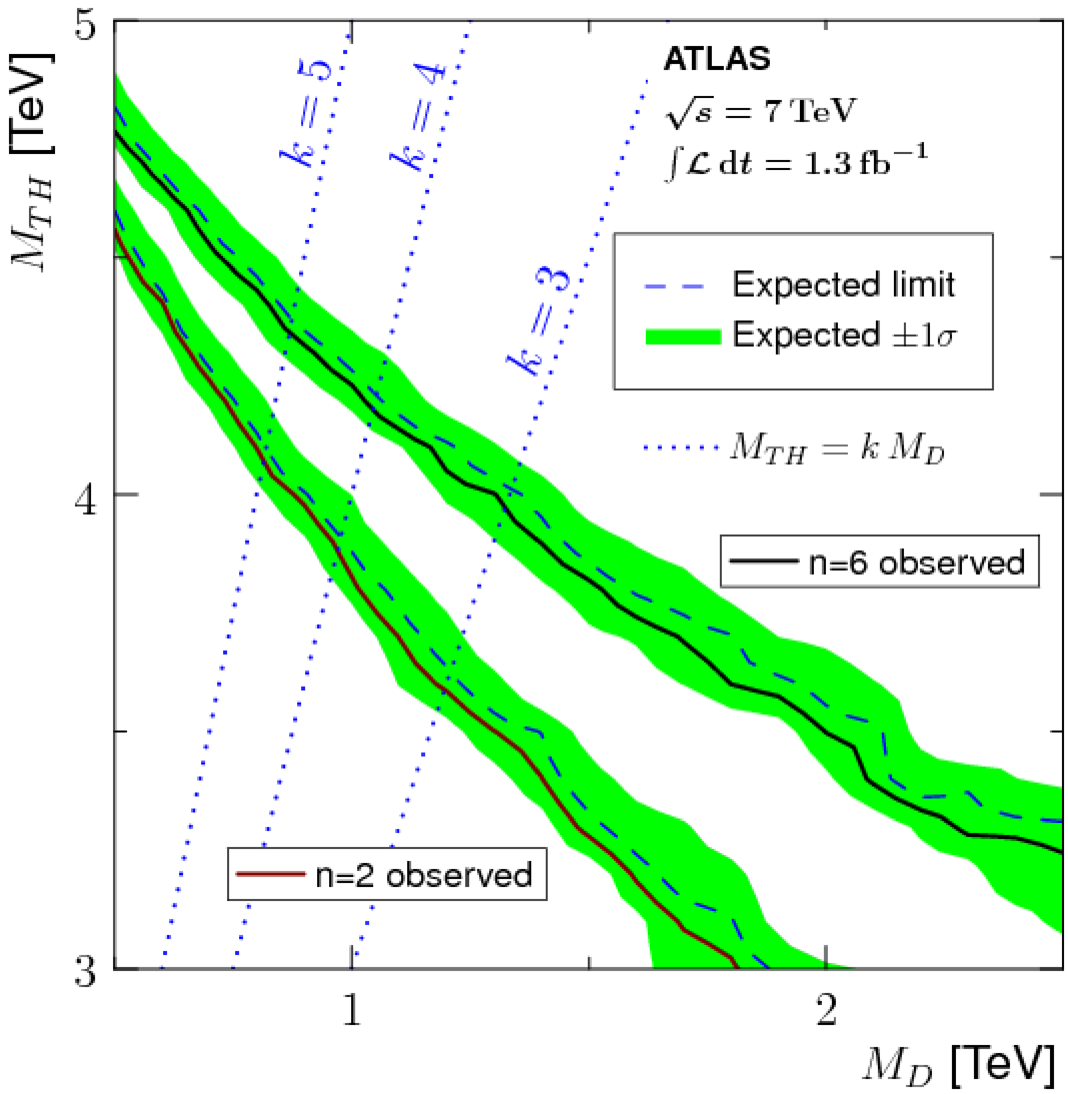
- Uncertainty due to scaling of truth acceptance.
- Uncertainty on luminosity.
- Uncertainty on acceptance due to PDF (CTEQ6.6 error sets).
- Uncertainty on acceptance due to muon trigger and identification.
- Statistical uncertainty on acceptance at each point.

Large uncertainties on signal cross section not included in limit calculation

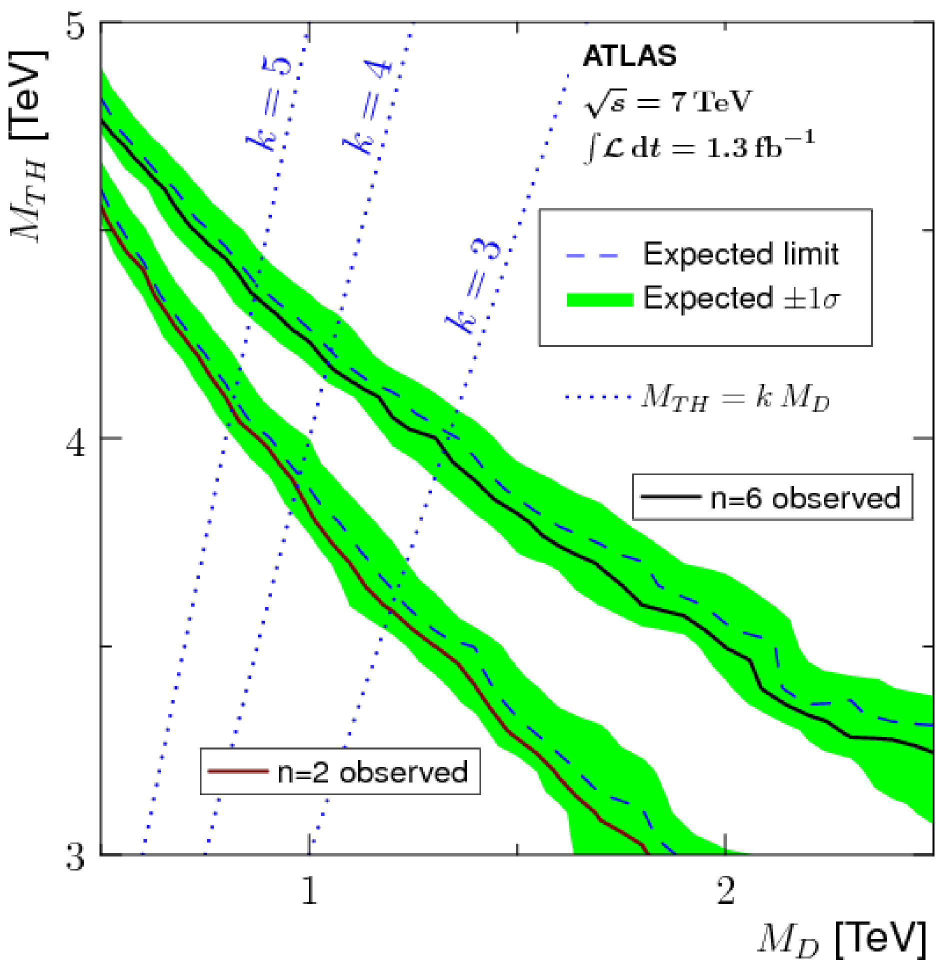
Non-rotating black holes with n = 6



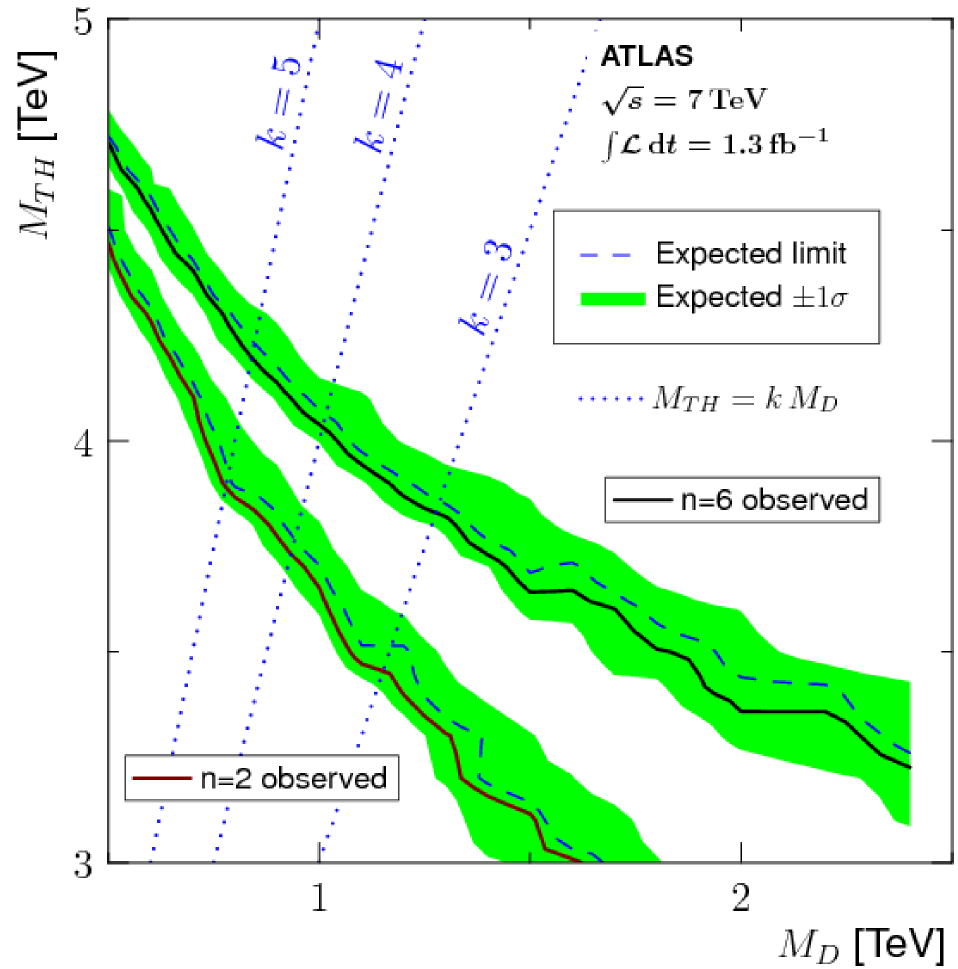
Non-rotating black holes with *n* = 6 , 2



Black holes with n = 6 , 2



Non-rotating black holes



Rotating black holes

Summary

Presented a black hole search at ATLAS.

Final state with like-sign dimuons and at least ten (10 GeV) tracks. http://arxiv.org/abs/1111.0080

No signal found.

Exclusion contours in the plane of M_D-M_{TH} for different *n* in different scenarios.

We're excluding M_{TH} < 4.5 TeV in almost all cases – sizeable fraction of $\sqrt{s}$.

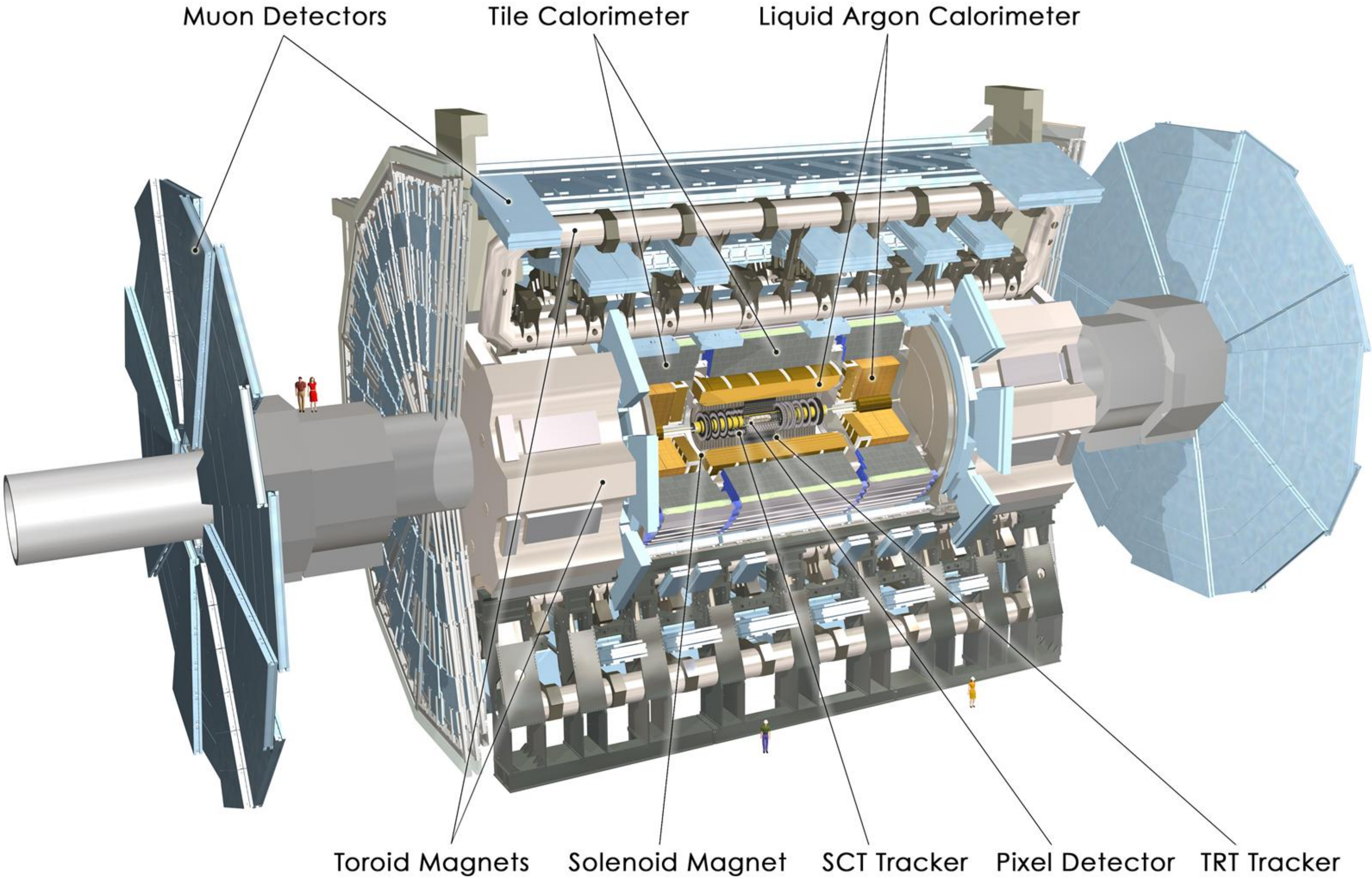
Need higher energy to significantly improve this.

Supplementary slides

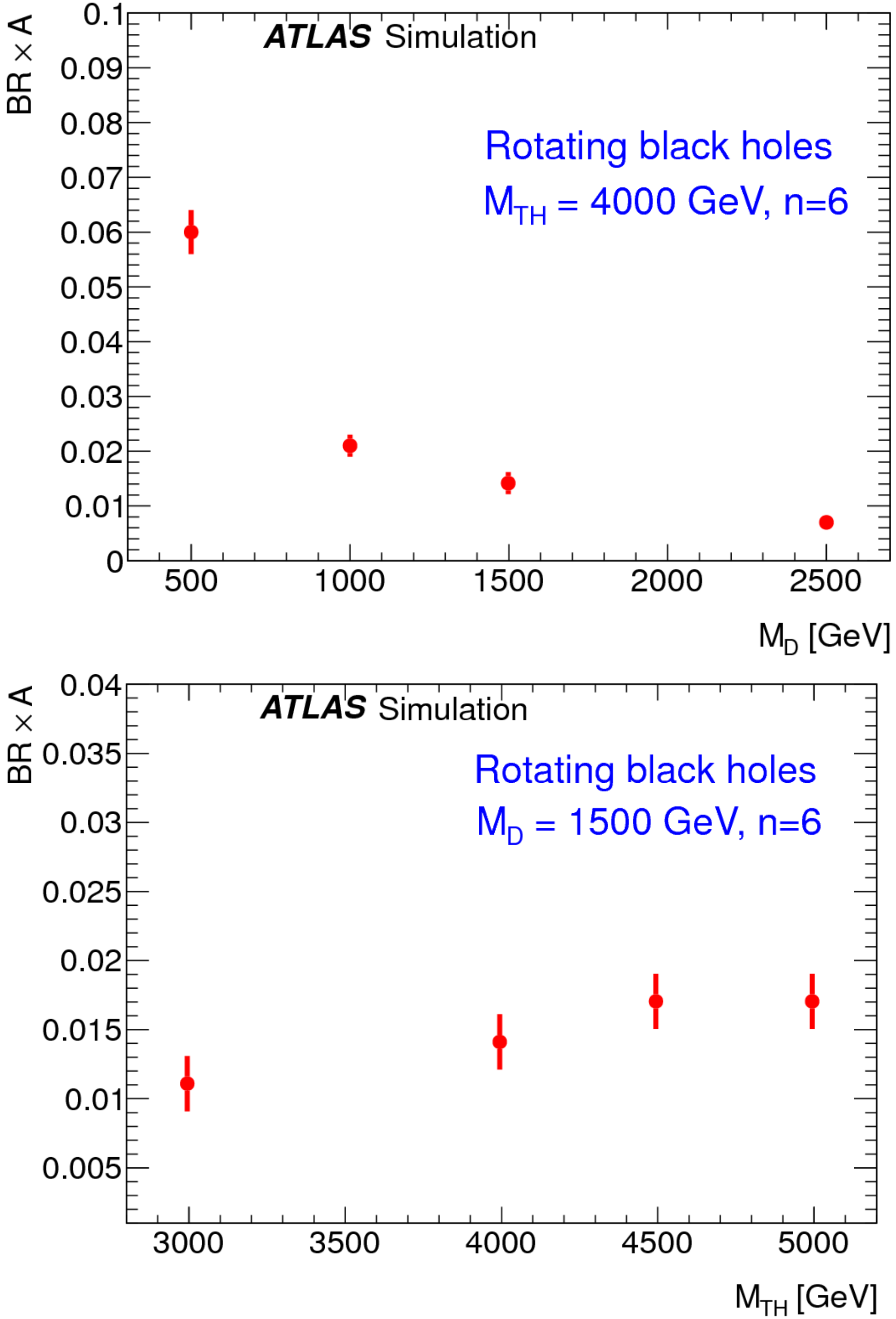
The ATLAS Detector

Muon Coverage: $|\eta|<2.7$
pT resolution < 10%

EM: $|\eta|<3.2$, $\sigma/E \sim 10\%/\sqrt{E}$
Had: $|\eta|<5$, central $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$, forward $\sigma/E \sim 90\%/\sqrt{E} \oplus 0.07$



Tracker Coverage: $|\eta|<2.5$
$\sigma/p_T \sim 3.8 \times 10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$



The branching ratio (BR) x acceptance (A) to the final state with two like-sign muons and ≥ 10 tracks used in this analysis for different rotating black hole signal models with n=6. The top plot shows the BR x A as a function of M_D for fixed M_{TH}, the bottom shows the BR x A as a function of M_{TH} for fixed M_D.

Bibliography...

Drop me a line at sdube AT lbl DOT gov for details.